

# A Direct Probe to the Electronic Structure of Interfaces in Heterostructure Semiconductors

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## INTRODUCTION

The characterization of interfaces is a key concept for understanding the properties of semiconductor devices. The large penetration length and site selectivity of soft-x-ray-emission (SXE) spectroscopy offer the possibilities of investigating the electronic structure of buried layers and their interfaces of heterostructure semiconductors.

Nilsson *et al.* measured Si *L* emission spectra of 1 and 3 ML thin Si buried under 100   thick GaAs (100) at the excitation energy of 120 eV. [1]

In the case of Si *L* SXE of Si/GaAs, the Si *L* and Ga *M* levels have almost same binding energy and thus the emission from two different atom sites overlaps in the same energy region. In order to draw out the information about Si layer, we subtracted a scaled Ga *M* SXE spectrum of bulk GaAs from Si/GaAs spectra. Figure 1 displays the difference spectra.

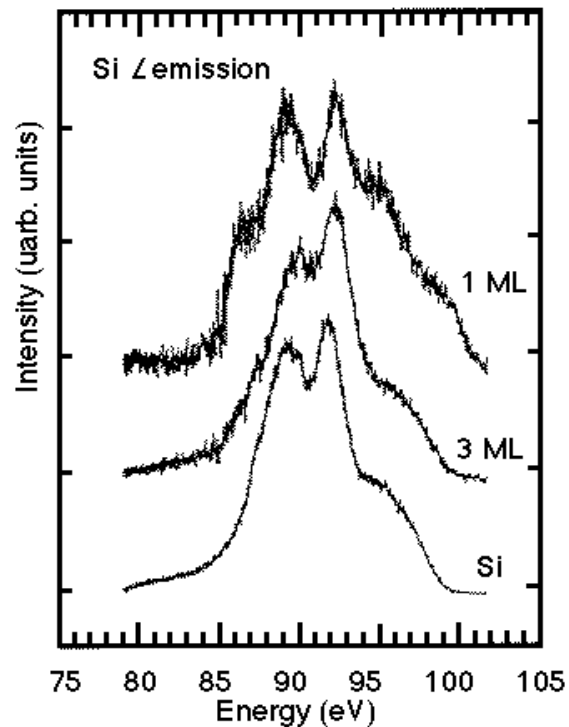


Figure 1. The Si *L* soft-x-ray-emission spectra subtracted by the Ga *M* spectrum of bulk GaAs from the 1- and 3-ML Si/GaAs buried under 100   GaAs(100) compared with bulk Si *L* emission spectrum. Photons of 120 eV were used for excitation.

The 1 ML spectrum shows bigger energy separation of main peaks than others and has humps around 86 and 95 eV at the both side of the main peaks. These features doesn't appear clearly in the 3 ML spectrum. These features are associated with a hybridising effect between the Si *s* states with the As *s* states.

We have measured Al *L* emission from 1, 2, 5 and 20 ML AlAs layers buried under 100   thick GaAs (100) capping layer. [2] Because the energy ranges of Al *L* emission and Ga *M* emission are separated, one can see the layer thickness effect for AlAs layers directly.

## EXPERIMENTAL

The soft-x-ray-emission spectra were recorded using a high-resolution grazing incidence x-ray fluorescence spectrometer [3] at beamline 7.0.

During the Al *L* SXE measurements, the resolution of the beamline was 0.12 eV and the resolution of the fluorescence spectrometer was set to 0.22 eV. The incidence angle of the photon beam was about 20 degree to the sample surface.

The heterostructures were grown by solid source molecule-beam epitaxy on GaAs (100) substrates and thin 1, 2, 5, and 20 ML AlAs layers were finally capped by a 100 Å thick GaAs layer. Because Al, like Ga, is a III-valued atom and AlAs has a similar lattice constant to that of GaAs, we have assumed that Al only occupies Ga-site.

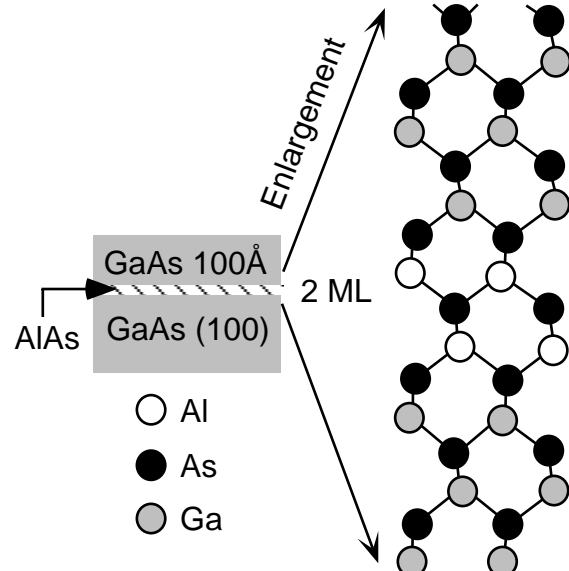


Figure 2. A schematic geometry from 2 ML-AlAs (100)-layers. Two unit cells side by side are displayed.

Figure 2 shows a schematic atomic geometry two unit cells side by side of 2 ML-AlAs (100)-layers. Al state of AlAs could be strongly effected the neighbour GaAs in the case of ultra thin AlAs layers and in the central layer in the thick layers Al should be like bulk state.

## RESULTS

Thick curves in Fig. 3 show the smoothed Al *L* SXE spectra of AlAs buried under the 100 Å thick GaAs(100) capping layer form heterostructures with 1-, 2-, 5-, and 20-ML-AlAs thin layers. Photons of 80 eV were used for excitation. Since AlAs layers were ultra thin, the Al *L* emission intensity was very weak. The error bars are shown on the left.

The 20-ML-spectrum is identical to a bulk spectrum [4], however thinner layers spectra show a dip at around 68.5 eV and the peak at 67.3 eV becomes broader. In the case of the 1 ML case, a hump appears at 66 eV (A). These distinct difference must be caused by interface effect between AlAs and GaAs. Thin curves show the *ab initio* theoretical calculations spectra. The top theoretical spectrum is calculated for bulk. The tendency of change of spectra shape depending layer thickness is well reproduced.

The spectral broadening is caused by appearing of B, and small peak A appears clearly only in the case of monolayer (1 ML) AlAs, this is expected to be effected form the neighbour Ga state through the As state. We interpret these features as a hybridized states at the interface. Peak A intermixed states are not found in 2 ML spectrum, thus this is a character of monolayer in the heterostructure. Hump B is observed in 2 ML spectrum as well. This is also assumed to be from hybridization effect with the surrounding.

In the thicker layers the Al *L* SXE spectra show bulk like spectra. The electronic structure is fully bulk like in the centre layer, Only at the interface the Al states strongly mix into the neighbour GaAs.

## CONCLUSION

This investigation demonstrates that it is feasible to study details of the electronic structure of internal ultra thin layers using soft x-ray emission spectroscopy. For the 1 ML case monolayer states are found to mix strongly into surrounding GaAs. Because the object to investigate is ultra thin and is buried under thick capping layers, the intensity of SXE spectrum is very weak. The high brilliant synchrotron is necessary for this kind of measurements.

## REFERENCES

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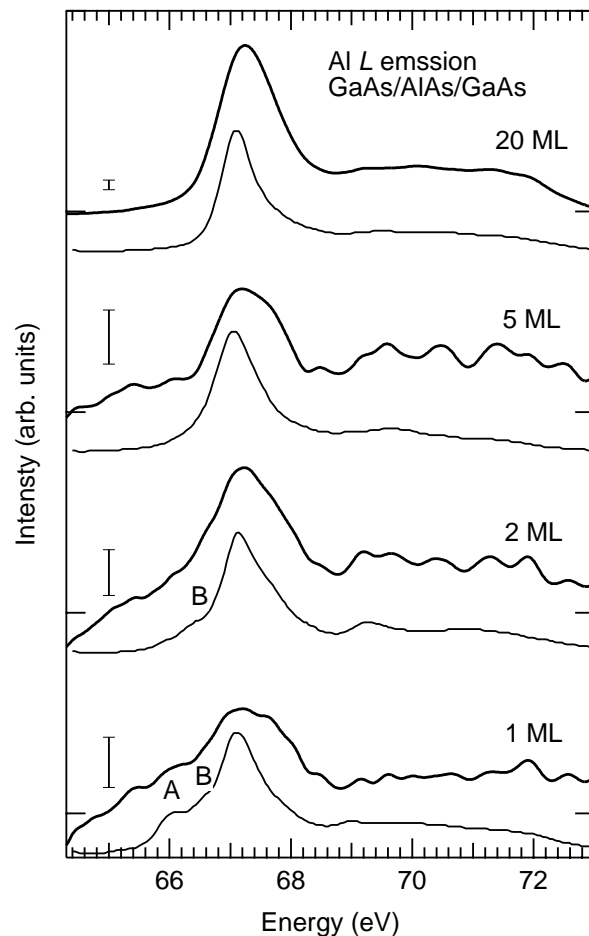


Figure 3. The smothed Al *L* soft-x-ray-emission spectra under 100Å GaAs(100) with various thickness of AlAs layers. Photons of 80 eV were used for excitation. The error bars are shown on the left.